https://erjm.journals.ekb.eg
ISSN: 1110-1180

DOI: ---------

ERJ
Engineering Research Journal
Faculty of Engineering
Menoufia University

Evaluating the Impact of Demand Side Management Techniques on Household Electricity Consumption, A real case

Heba A. Khattab[1], Fatma F. Awad, and Asmaa F. Nasef [1*]

[1]*Department of Electrical Eng., Faculty of Eng., Menoufia University, Egypt.*
[2] *MS.C. Candidate (Corresponding author: ASMAA.NASEF@sh-eng.menofia.edu.eg)*

ABSTRACT

Demand Side Management (DSM) is a very important tool that converts a consumer's passive role to an active one by changing energy consumption and helps the energy utilities to decrease the peak demand and reshape the load curve. This paper presents a detailed analysis of the impacts of three of the most important DSM techniques which are energy efficiency, direct load control, and shifting load through two cases for one day in summer and one day in winter. The effectiveness of the three techniques is demonstrated on an average daily consumption of an Egyptian residential house in Shebin El-Kom, Menoufia Governorate. The desired objectives are reducing the energy consumption, electricity bill, and minimizing peak to average ratio (PAR). The obtained results confirm that applying DSM techniques has significant potential in terms of financial savings for the consumers and utility provider, and a cleaner environment without any impact on service quality or customer satisfaction.

Keywords*: Demand Side Management (DSM), Energy Efficiency (EE), Direct Load Control (DLC), Load Shifting, and Peak to Average Ratio (PAR).*

1. Introduction

In Egypt, electricity consumption is growing continuously because of increasing population and development needs [1-4]. Egypt's energy sector faces challenges in facing electricity demand among all sectors (agriculture, industry, services, and residential), the rate of electricity consumption in Egypt has increased by 7% annually during the past three decades [4]. The residential sector was the largest energy consumption that was responsible for more than half of the total energy consumption in Egypt according to the last report from the Egyptian authority [5,6]. According to that increase in consumption, electricity production should be increased also. So, sources use more fossil fuels to generate electricity which in turn increases the level of carbon dioxide in the atmosphere. Moreover, the electrical system becomes unreliable during peak hours, the production and transmission capacity are insufficient to meet the increase in demand, and the infrastructure of the electricity system is outdated [1-4]. One of the solutions to solve the previous problems is to implement Demand Side Management (DSM) techniques [7,8].

DSM is done by planning, implementing, and developing activities to influence customer's use of electricity, so as to produce the desired daily or seasonal load shapes [9-12]. For utility, DSM means avoiding or delaying the need to construct new generating units, reducing capital investments, and ensuring efficient operation in the generation, transmission, and distribution. For residential consumers, DSM means reduced bills. DSM is a set of interactive programs that give a customer a greater role in shifting its consumptions to off-peak periods, decreasing the total electricity bills while giving lower costs per kWh to utilities [12].

Mainly six techniques are popularly used for demand management to enhance the load shape which are load shifting, peak clipping, conservation, load building, valley filling, and flexible load shape [13,14]. These techniques are illustrated in Figure (1), which are different from one utility to another, depending on the number of customers, nature of the load type, the level of customers' reaction or satisfaction with the applied technique, etc. [12].

In [11,15,16], rescheduling of the load curve of a consumer from the current load curve is performed as a DSM strategy. The former is done depend on a time-based pricing method that would reduce the PAR of the end-user. This scheduling is also dependent on categorizing the devices used by the consumer as shiftable and non-shiftable loads. In [2,4,8,17], the impact of the DSM strategy on load was investigated with renewable energy sources. The pricing model was presented as a more effective alternative. In [1,4,18], the ability of the energy-saving behavior as a DSM strategy has been explored in the reduction of developed economies. This study suggested that energy-saving behavior could reduce energy demand by a maximum of 21.9% and the energy efficiency strategy could reduce electricity demand in the residential sector by about 28.8%.

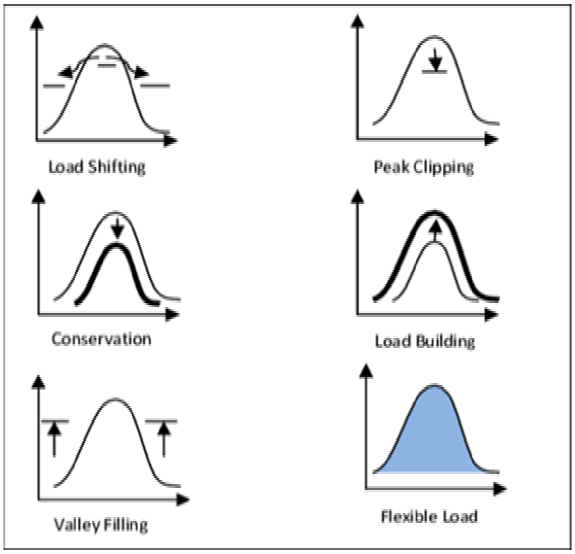

Figure 1-Demand Side Management Techniques

In this paper, the average load curve for a household load in Shebin El-Kom City, Menoufia Governorate is investigated. Then, applying DSM techniques such as energy efficiency, direct load control, and shifting load to reduce daily energy consumption, minimization of electricity cost, and peak to average ratio (PAR). The approaches of DSM are examined in section II, section III introduces the load categories, section IV focuses on the proposed DSM strategy, and the simulation results are discussed in section V. Finally, section VI summarizes the main conclusions.

2. Approach to DSM

DSM can be classified into two main parts as Energy Efficiency (EE), and Demand Response (DR). Demand response can be divided into a time of use, direct load control, and load shifting. Figure (2) shows the general classification of DSM [7,19,20]. Three techniques are used in this study which are energy efficiency, direct load control, and load shifting. Each technique is explained as follows:

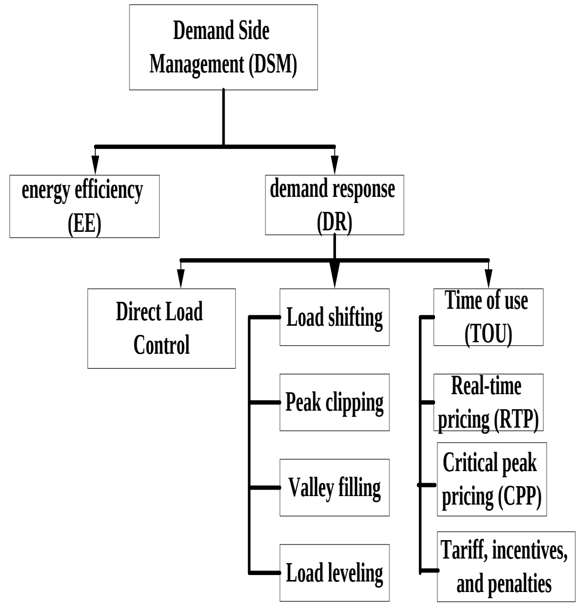

Figure 2-Classification of DSM

2.1 Energy Efficiency

Energy efficiency technique is very important in power systems where it is required to decrease the overall energy consumption by replacing normal appliances with energy-efficient appliances [21, 22]. Energy-efficient appliances use less electricity to achieve the same level of performance as similar models with the same size or capacity. The more efficient the model, the less its energy consumption and its operating cost [23].

2.2 Direct load control

Direct load control technique is aimed at decreasing the demand during peak hours, especially if the installed capacity is not enough to cover the peak demand. Not all devices are suitable for direct load control. Devices like refrigeration load, heating, and cooling devices are suitable for direct load control technique. Maximum interruption is between 30 minutes to 1 hour that can be applied 2-3 times a day [7, 24].

2.3 Load Shifting

Load shifting is one of the best techniques used in Demand Side Management (DSM) by shifting the loads from peak hours to off peak hours. It does not make any change in the amount of consumed energy but reducing the peak loads in the network demand pattern [25, 26].

3. Load Categorization

According to the energy consumption pattern, operating time, and user preference, the appliances are categorized into three broad classes: regularly operated appliances, shiftable, and elastic appliances. Each category is explained as in [27,28]. The power consumption (E) of these appliances is represented as [29]:

$$E = \sum_{t=1}^{T} \sum_{i \in ap} \rho_i \ sv_i(t) \tag{1}$$

Where ρ_i is the power rating of each appliance, T represents total time slots, $sv_i(t)$ is the state of each appliance in particular time slot 't' which is given as:

$$sv_i(t) = \begin{cases} 0 \ if \text{ appliance is OFF} \\ 1 \ if \text{ appliance is ON} \end{cases} \tag{2}$$

3.1 Regularly operated appliances

Regularly operated appliances or fixed appliances are those devices that must be run at the ideal times specified by the users. The energy consumption pattern and overall operation time of these devices cannot be changed [27].

3.2 Shift-able appliances

These are the loads that can perform their work at any instant of time but the operation should not be interrupted after starting, however, their runtime must be completed [27,29]. They are also named as burst load.

3.3 Elastic appliances

These loads are considered as flexible appliances, their time period and energy consumption profile are flexibly adjusted. These devices can be switched on at any time and can be cut off while they are running [27, 29].

4. Proposed DSM Strategy

This section introduces two subsections that described subsequently:

4.1 Household electricity consumption model

The total energy consumption and the total cost per day are computed as [27]:

$$E_{A_n,T} = \sum_{t=1}^{T} \left(\sum_{1}^{A_n} P_{A_n}^{t} * \tau(t) \right) \tag{3}$$

$$C_{A_n}^{T} = \sum_{t=1}^{T} \left(\sum_{1}^{A_n} P_{A_n}^{t} * \varepsilon(t) * \tau(t) \right) \tag{4}$$

Suppose (A_n) represents a set of appliances, while P_{A_n} is the power rating of appliances, E_{A_n} is the total energy consumption in a day where T equals 24 hours, and $C_{A_n}^{T}$ is the total consumption cost per day.

Where $\tau(t)$ isthe number of appliances operating hours per day and $\boldsymbol{\varepsilon}(t)$ is the price of energy consumption kilowatt hour (L.E/kWh).

PAR is defined as the ratio between peak load over average loads in a given time frame that can be written as follows [30]:

$$PAR = \frac{max\left(E_{A_n}\right)}{1/T \sum_{t=1}^{T} E_{A_n,T}} \tag{5}$$

The high value of PAR threatens grid stability and increases electricity cost. While the reduction in PAR, simultaneously enhances the stability and reliability of the power grids and reduces the electricity bill of the consumers [15,16].

4.2 Egyptian Household Energy Consumption

For our study, the average consumption of a real house in Stadium Street in Shebin El-Kom is analyzed through monthly bills and daily consumption in two cases namely one day in the summer and another day in the winter season.

According to the report of the Egyptian electricity company [5], the following electricity segment prices for the new fiscal year 2020/2021 are listed in Table (1).

Table 1- Prices of electricity in 2020/2021

Monthly Consumption kWh/ month	Tariff Egypt (L.E)
KWh 50 – 0	0.38
KWh 100– 51	0.48
KWh 200 – 0	0.65
KWh 350 –201	0.96
KWh 650 – 351	1.18
to less than 1000 KWh 0	1.18
to more than 1000 KWh 0	1.45

Table (2) shows the most common household appliances that will be used in this study where household appliances differ from one house to another, from one residential area to another, from one standard of living to another, and from one season to another.

Table 2- The list of consumption of major home appliances

eApplianc	Range of consumpt -ion (Watt) [5],[23]	Power consump tion - (Watt)	No. of Operation hours of appliances (Hour)
Fluorescent Lamp	60 - 20	40	10
Energy saving bulbs	27 - 2	25	8
Television (TV)	250 - 100	100	4
Refrigerato r-	800 - 56	350	24
Freezer	800 - 56	275	15
Microwave	- 800 1200	1050	2
Electric heater	- 1000 2000	1000	4
Washing machine	700 - 500	500	2
Dishwasher	-1200 2400	1200	1
Water heater	- 1000 5000	1000	6
Computer (PC)	200 - 100	150	3
Air Conditioner (AC)	- 1000 3000	1200	6
Fan	100 - 60	100	8
Iron	- 600 1310	1000	0.5

Two cases studied are presented as:

Case 1:
Figure (3) shows the average daily load curve in the pattern of using loads of a household in summer season where the average consumption is 983 kWh/month with an average load per day 32.75 KWh/day. From the load curve, it can be seen that the peak consumption occurs from 8:00 pm to 11:00 pm which is confirmed with the report of the Egyptian electricity company) [5].

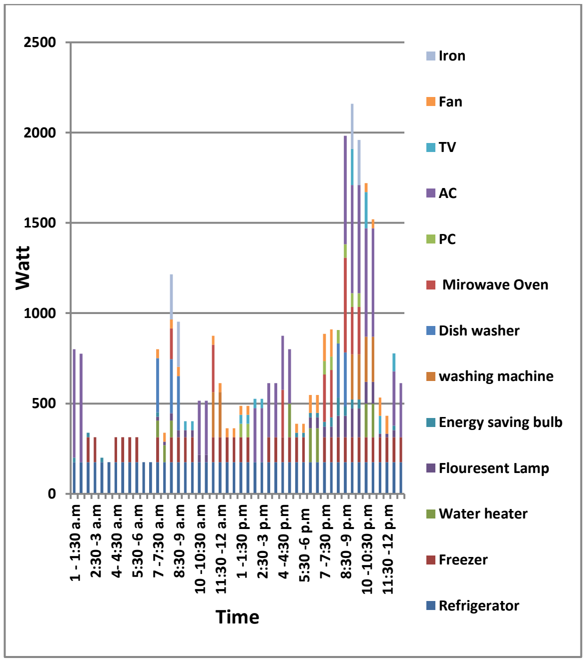

Figure 3- Daily average load curve for case 1

Case 2:
The average daily load curve in winter is presented in Figure (4) where the average consumption is 422 kWh/month with average load per day 14.1 KWh/day. From this curve, it can be seen that the peak consumption occurs during the period of 5:00 pm to 9 pm.

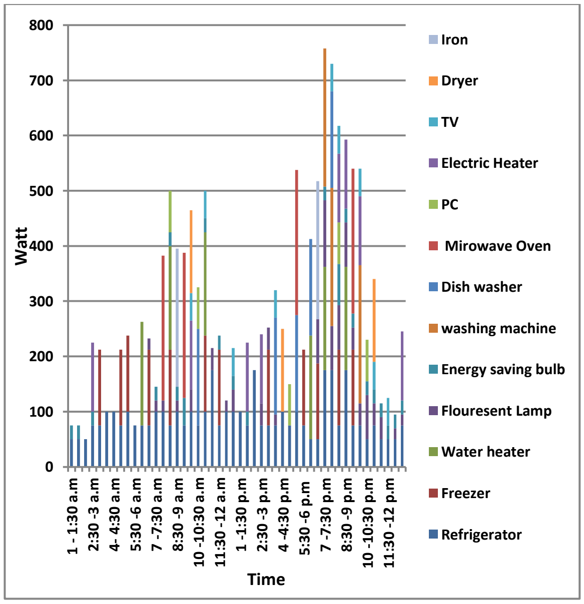

Figure 4- Daily average load curve for case 2

It is noticed that the consumption in the summer and holidays season differs from the consumption in the winter and school season. User habits of some appliances' usage are quite similar in the summer and winter time, such as refrigerator, PC, some small kitchen appliances, hairdryer, TV, and others. The consumption falls in the middle of the day and in the evening consumption again increases when people return home after work. Some appliances are kept on all day long whereas some appliances are used for a limited period [20, 21]. Energy consumption due to air conditioners, refrigerators, and freezer turn out are the largest share in energy consumption in summer case while in winter case the water heater and the electric heater turns out are the largest share in energy consumption.

5. RESULTS and DISCUSSION

In each case, the impacts of energy efficiency, direct load control, and load shifting are analyzed on the average daily load curve, monthly consumption (KWh), electricity bill, and on the peak to average ratio (PAR) are presented and discussed.

5.1 Effect of Energy Efficiency (EE) Technique

In this technique, the refrigerator, light, and television loads are replaced by energy-saving loads as shown in Table (3) and the effect of these changes on the average daily load curve, thus on electricity consumption and the electricity bill is studied.

Table 3- Energy consumption of the replaced appliances

Appliances	Energy consumptio-n of old appliances (Watt)	Energy consumption of an efficient ones (Watt)
Refrigerator	350	100
Fluorescent lamp	40	LED tube light 18Watt
saving -Energy bulb	25	LED bulb light 12Watt
Fan	100	32
TV	100	48

Figures. (5) and (6) show the resulted load curve when replacing the mentioned appliances in Table (3) with an energy-efficient one for both cases. Table (4) illustrates the effect of energy efficiency for both cases. It can be observed that applying the energy efficiency technique increases the monthly consumption savings by 26 % and 29.3 % in the summer and winter seasons respectively. Also, the electricity bill savings are 25.5 % and 37 % in the summer and winter seasons respectively. The PAR factor is slightly decreased due to the reduction in both peak and average consumption.

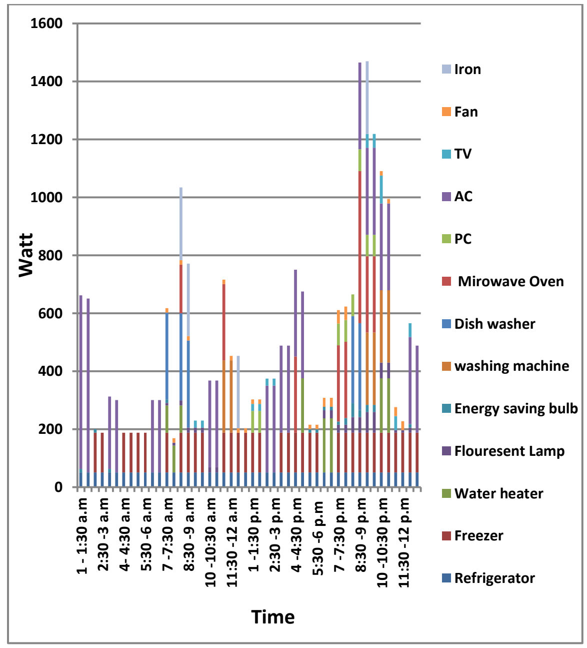

Figure 5- Daily average load curve after applying EE for case 1.

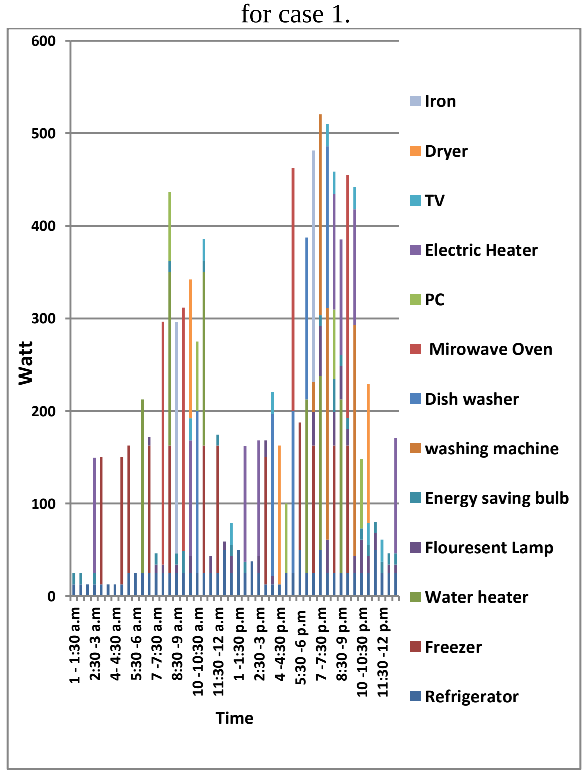

Figure 6-Daily average load curve after applying EE for case 2.

Table 4- The obtained results of applying EE technique

		Before applied EE	After applied EE
Monthly Consumption (KWh)	Case 1	983	727.3
	Case 2	422	298.4
Electricity bill (L.E)	Case 1	1184.94	883.2
	Case 2	373.96	235.46
Peak of consumption (Watt)	Case 1	2160	1469
	Case 2	757.5	520.5
Daily average of consumption (Watt)	Case 1	682.3	495
	Case 2	293	207.2
(%) PAR	Case 1	3.16	2.97
	Case 2	2.6	2.5

5.2 Effect of direct load control (DLC) Technique
According to the direct load control method, some particular loads are turned off for a limited time. By applying this DSM technique, some amount of energy can be saved every day. The summer and :winter cases are studied as

- In the summer case, the freezer is kept off from 8:30 pm to 9:00 pm. Air Conditioner (AC) is kept off from 8:00 pm - 8:30 pm and from 9:00 pm -9:30 pm. Also, the water heater is kept off from 10:00 pm to 10:30 pm.

The resulted daily average load curve is shown in Figure (7) for the summer case While, for winter day the appliances which are kept off are:

- The refrigerator is kept off from 7:00 pm to 7:30 pm., and the water heater is kept off from 7:00 pm to 7:30 pm and from 8:30 pm -9:00 pm. The electric heater is kept off from 8:00 pm to 8:30 pm and from 9:30 pm to 10:00 pm.

The resulted daily average load curve is shown in Figure (8) and Table (5) illustrates the effect of the DLC technique for both cases. It can be concluded that the PAR ratio is decreased, the monthly consumption savings are increased by 5.4 % and 5.9 % also, the electricity bill savings are 5.3 % and 8.95 % in the summer and winter cases, respectively.

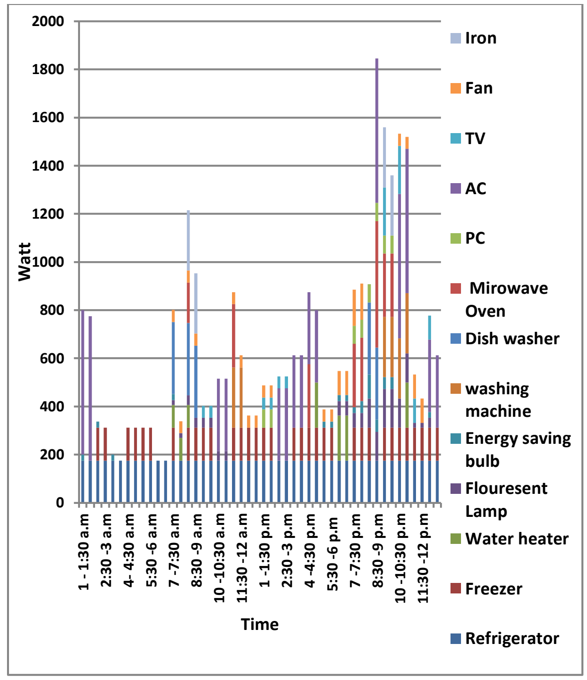

Figure 7- Daily average load curve after applying DLC for case 1.

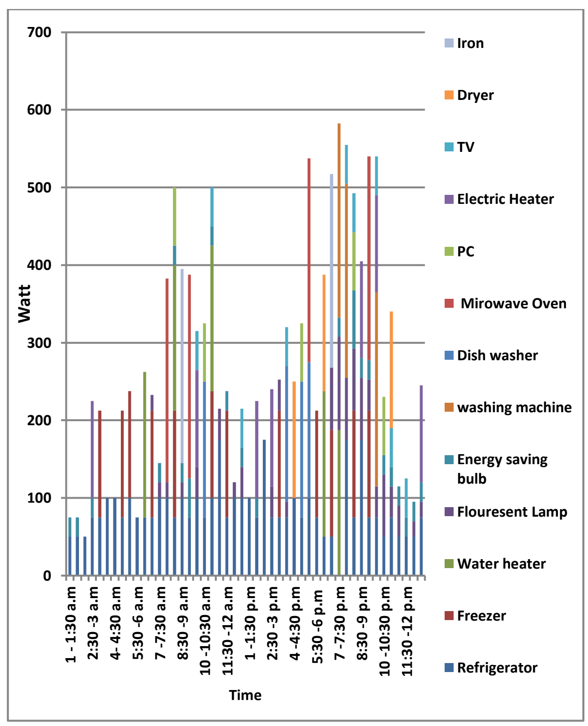

Figure 8- Daily average load curve after applying DLC for case 2

Table 5- The obtained results of applying DLC technique

		Before applied DLC	After applied DLC
Monthly Consumption (KWh)	Case 1	983	930
	Case 2	422	397
Electricity bill (L.E)	Case 1	1184.94	1122.4
	Case 2	373.96	340.46
Peak of consumption (Watt)	Case 1	2160	1845
	Case 2	757.5	582.5
Average of consumption (Watt)	Case 1	682.3	650.5
	Case 2	293	279.2
(%) PAR	Case 1	3.16	2.8
	Case 2	2.6	2.1

5.3 Effect of Load shifting Technique

Water heater, washing machine, dish washer, microwave oven, and iron can be shifted from peak hour to off-peak hour.

- The load curve after shifting the water heater from (6 p.m-7 p.m.) to (12 a.m-1 p.m.), washing machine from (9 p.m-10 p.m.) to (6 a.m-7 a.m.) and iron from (9: 30 p.m-10 p.m.) to (12 a.m-12: 30 a.m.) is shown in Figure (9) for case 1.
- While for case 2, the water heater shifted from (7 p.m. - 7: 30 p.m.) to (3: 30 p.m. – 4 p.m.), washing machine shifted from (7 p.m. – 8 p.m.) to (12: 30 a.m-1: 30 p.m.), electric heater shifted from (8 p.m. - 8: 30 p.m.) to (4 p.m. - 4: 30 p.m.), and dryer shifted from (6 p.m. - 6: 30 p.m.) to (5 a.m. - 5: 30 a.m.)، where the shifted load curve is shown in Figure (10).

Table (6) illustrates the effect of the load shifting technique in both cases, it concluded that:

- The consumption distribution throughout the day is almost uniform, so the average consumption is constant and the peak load demand is reduced.
- A large decrease in PAR value, which leads to enhancing the stability and reliability of power networks.

Table 6- The obtained results of applying load shifting technique.

		Before applied load shifting	After applied load shifting
Peak of consumption (Watt)	Case 1	2160	1397.5
	Case 2	757.5	592.5
(%) PAR	Case 1	3.16	2.0
	Case 2	2.6	2

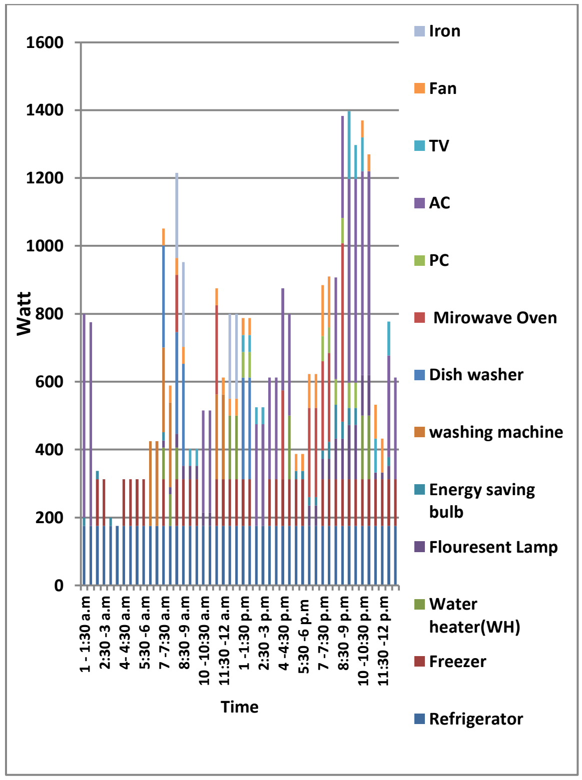

Figure 9- Daily load curve after applying load shifting for case 1

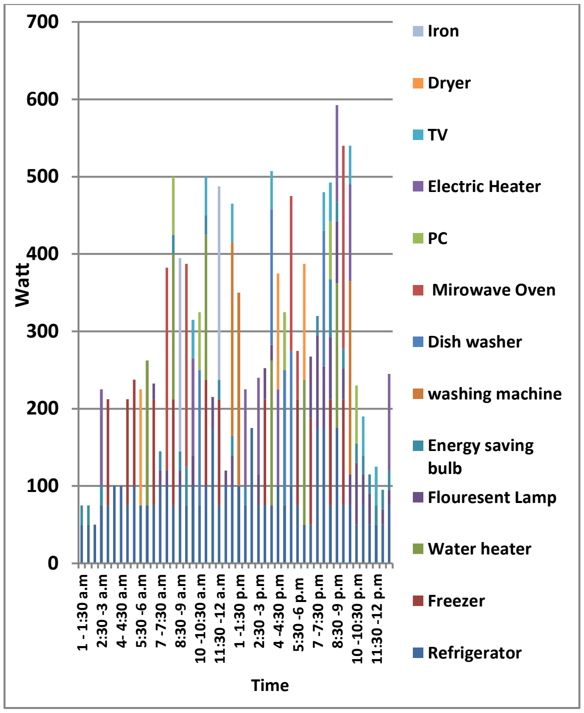

Figure 10- Daily load curve after applying load shifting for case 2

6. CONCLUSIONS

The electricity consumption of a residential house at Stadium Street in Shebin El-Kom, Menoufia Governorate when applying DSM based on energy efficiency, direct load control, and shifting load have been analyzed. The electricity consumption of two cases study have been obtained for one day in winter and other in summer. is concluded From the results, it :that

- Noticeable amount of energy can be saved by replacing normal appliances with energy efficient appliances. So, this technique should be given priority to reduce energy consumption.
- The direct load control technique is not the best among the other two technologies in terms of reducing consumption and saving electricity bills.
- The load shifting technique displays a better result by reducing the PAR ratio where the reduction in PAR and enhances the stability and reliability of the power grids.

So, DSM can change the thinking of constructing a new plant to meet the demand and defers high investment to setup transmission and distribution networks.

6. References

[1] Dalia M. Ibrahiem, " Investigating the causal relationship between electricity consumption and sectorial outputs: evidence from Egypt" Energy Transitions Journal, V. 12, No. 2, 2018, pp. 31- 48.

[2] Md. A. Hossain, R. Claudia, P. Al-Riffai, H. Eldidi, B. Clemens, and W. Manfred, “Long-Term Optimization of Egypt’s Power Sector: Policy Implications” Energy Journal, V. 166, 1 January 2019, pp. 1063-1073.

[3] H. Abdalla,” The Energy Situation in the Arab Republic of Egypt” Natural Resources Forum (John Wiley and Sons), V. 6, No. 1, 1982, pp. 43-51.

[4] Hosni E. Kholy, and F. Ragy, “Managing the Growing Energy Demand: The Case of Egypt” Energy & Environment Journal, V. 22, No. 5, 2011, pp. 553-563.

[5] "Egyptian Electricity Holding Company (EEHC) "Annual Report, 2014-2015, Available online; http://www.moee.gov.eg/english_new/EEHC_Rep/2014-2015en.pdf.

[6] Abdullah M. Elsayed, Mohamed M. Hegab, and Sobhy M. Farrag, “Smart residential load management technique for distribution systems' performance enhancement and consumers' satisfaction achievement” International Transaction on Electrical Energy System,V. 29, No. 3 ,2019.

[7] Ayman U. Mahin, Adnan Md. Sakib , Asif Md. zaman, Shahed Md. Chowdhury, and Saik A. Shanto, “Developing Demand Side Management Program for Residential Electricity Consumers of Dhaka City” International Conference on Electrical, Computer and Communication Engineering (ECCE), 16-18 Feb, 2017.

[8] John S. Vardakas, N. Zorba, and Christos V. Verikoukis, “A survey on demand response programs in smart grids: Pricing methods and optimization algorithms” IEEE Communication Surveys and Tutorials, V. 17, No. 1, 2015, pp. 152–178.

[9] Jin H. Kim, and Anastasia S .bakova, "Common failures of demand response" Energy, V. 36, No. 2, Feb. 2011, pp. 873-880.

[10] L. Thillainathan, S. Dipti, and Shun T. Zong, "Demand Side Management in Smart Grid Using Heuristic Optimization" IEEE Transactions on Smart Grid Journal, V. 3, No. 3, Sept. 2012, pp. 1244 – 1252.

[11] D. Javor, and A. Janjic, “Application of Demand Side Management Techniques in Successive Optimization Procedures” International Journal of Communications in

Dependability and Quality Management, V. 19, No. 4, 2016, pp. 40-51.

[12] D. Javor, and A. Janjić, "Using Optimization Tools for Solving Demand Side Management Problems" 2nd Virtual International Conference on Science, Technology and Management in Energy, 2016.

[13] K. Swathi, B. Kishore, and V. Muthuvel, "Residential Load Management Optimization in Smart Grid" International Journal for Trends in Engineering & Technology, V. 13, No. 1, May 2016.

[14] Hussein A. Attia, "Mathematical formulation of the Demand side management (DSM) problem and its optimal solution" Proceedings of the 14th International Middle East Power Systems Conference (MEPCON'10), Cairo University, Egypt, 19-21 Dec., 2010.

[15] R. Rajarajeswari, K. Vijayakumar, and M. Ashutosh," Demand Side Management in Smart Grid using Optimization Technique for Residential, Commercial and Industrial Load" Indian Journal of Science and Technology, V. 9, No. 43, 2016.

[16] Muhammad B. Rasheed, N. Javaid, M. Awais, and Zahoor A. Khan, "Real time information-based energy management using customer preferences and dynamic pricing in smart homes" Energies, V. 9, No. 7, 2016.

[17] Vikas A. Vatul, Arputha N. Aravinth, and N. Krishnan," Demand Side Management: A different pricing Model" IEEE 1st International Conference on Energy, Systems and Information Processing (ICESIP), 2019.

[18] I. Khan, "Energy-saving behavior as a demand-side management strategy in the developing world: the case of Bangladesh" International Journal of Energy and Environmental Engineering, April 2019.

[19] Mahdi M. Legha, M. Afsharmanesh," Demand Management in a Microgrid Using Particle Swarm Optimization (PSO)" Specialty journal of Engineering and Applied Science, V. 1, No.1, 2016, pp. 47-55.

[20] K. Kostkova, L. Omelina, P. Kycina, and P. Jamrich, "An introduction to load management" Electric Power Systems Research, V. 95, Feb 2013, pp. 184-191.

[21] Simon P. Borg, and N. J. Kelly, "The effect of appliance energy efficiency improvements on domestic electric loads in European households" Energy and Buildings Journal, V. 43, No. 9, 2011, pp. 2240–2250.

[22] Ma. Jinghuan, He H. Chen, Li. Song, and Li. Yonghui," Residential load scheduling in smart grid: A cost efficiency perspective" IEEE Transactions on Smart Grid, V. 7, No. 2, 2016, pp. 771–784.

[23] I. Laicane, D. BLumberga, A. BLumberga, and M. Rosa," Evaluation of household electricity savings. Analysis of household electricity demand profile and user activities" Energy Procedia, V. 72, 2015, pp. 285 – 292.

[24] S. Reka, and V. Ramesh, "A demand response modeling for residential consumers in smart grid environment using game theory-based energy scheduling algorithm" Ain Shams Engineering Journal, V. 7, No. 2, 2016, pp. 835-845.

[25] M. Blecourt, and M. Grond, "Load-shifting in a new perspective" Faculty of Technology, Policy and Management, January, 2012.

[26] Siva S. Kumar, and Gopichand M. Naik, "Load Shifting Technique on 24Hour Basis for a Smart-Grid to Reduce Cost and Peak Demand Using Particle Swarm Optimization" International Research Journal of Engineering and Technology (IRJET), V. 4, No. 10, Oct 2017.

[27] Hu. Hafiz, Ja. Nadeem, Iq. Sohail, Ha. Qadeer, and Au. Khursheed," An Efficient Demand Side Management System with a New Optimized Home Energy Management Controller in Smart Grid" Energies, V. 11, No. 1, 2018.

[28] M. Seokjae, and Lee J. Won, "Multi-Residential Demand Response Scheduling with Multi-Class Appliances in Smart Grid"IEEE Transactions on Smart Grid, V. 9, No. 4, 2016, pp. 2518 – 2528.

[29] Zahoor A. Khan, A. Zafar, S. Javaid, Rahim M. Hassan, and Sh. Aslam, "Hybrid meta-heuristic optimization-based home energy management system in smart grid" Journal of Ambient Intelligence and Humanized Computing, V. 10, No. 4, 5 April 2019.

[30] B. Leonard, and T. Olivier, "An Efficient Scheduling of Electrical Appliance in Micro Grid Based on Heuristic Techniques" Conference on Complex, Intelligent, and Software Intensive Systems (CISIS), V. 611, 2017, pp. 164-173.